Reconstruction of Past Sea Level Change from a Combination of Satellite Altimeter and Tide Gauge Measurements

R. S. Nerem
Cooperative Institute for Research in Environmental Sciences
University of Colorado at Boulder

PROJECT SUMMARY

There are two primary datasets that are used for measuring sea level change. Tide gauge measurements provide estimates of sea level change over the past century, but with relatively poor spatial sampling (Figure 1). The tide gauge data have shown an average rate of sea level rise of ~1.8 mm/year over the last 70 years. Satellite altimeter measurements from the TOPEX/Poseidon (T/P) and Jason satellites provide precise global measurements of sea level since 1992, but the record is relatively short. T/P and Jason have observed a rise of global mean sea level of +3.2 ± 0.4 mm/year (Figure 2) [*Nerem and Mitchum,* 2001a; *Nerem and Mitchum*, 2001b]. While this result is reasonably certain, critical questions still exist about the interpretation of this result in the context of long-term climate variations. Uncertainties in the interpretation of the tide gauge record make it difficult to determine if the altimeter-derived rate represents a significant acceleration of sea level rise relative to the historical record. The tide gauge record is over a century long, but suffers from poor spatial distribution and uneven coverage in time. The altimeter record is relatively short, but has excellent near-global coverage. Therefore, it is natural to consider trying to take advantage of the best features of each dataset to investigate long-term sea level change.

The primary purpose of our research is to develop improved techniques for reconstructing sea level change over the past century using a combination of tide gauge measurements and satellite altimeter data. There has been considerable interest recently in reconstructing past sea level change [*Chambers, et al.,* 2002; *Church and White,* 2006]. There are a variety of different ways to combine altimeter and tide gauge sea level measurements to reconstruct past sea level change. We have been examining the advantages and disadvantages of different reconstruction techniques in order to select an optimal approach. However, all of these techniques are limited by the relatively short altimeter sea level record. This is because the variance of the altimeter record does not span the variance of the sea level record over the last century. Fortunately, as the altimeter time series lengthens, the results from the reconstruction techniques will improve.

The basic reconstruction method is summarized in Figure 3. An Empirical Orthogonal Function (EOF) analysis is used to decompose the gridded altimeter sea level maps into a series of dominant spatial and temporal modes. The temporal modes are discarded and the spatial modes are retained. The tide gauge data are then projected on to the spatial map in order to reconstruct the temporal modes over the entire length of the available tide gauge record.

Recently, *Church and White* [2006] used a similar reconstruction over the past century and claimed to have detected an acceleration in sea level rise. While this is an interesting result, it should be regarded with caution due to the limitations of the reconstruction technique. One of the limitations of this result is that it depends on sea level measured by only a half dozen tide gauges at the beginning of the 20th century. The varying distribution of the tide gauges as a function of time and space is an issue we plan to investigate further. Among the issues we plan to investigate are:

1) The uneven distribution of the tide gauges in both space and time.
2) The relative weighting of the tide gauges in the reconstruction process.
3) The treatment of the altimeter data in the reconstruction process (number of EOFs, smoothing, etc.)
4) Investigation of different reconstruction methods.

As part of this research, we plan to develop improved techniques for reconstructing past sea level change. In addition, we plan to develop a realistic description of the errors in these reconstructions, which has not been done in past studies. Determining the errors in these sea level reconstructions is critically important if the results are to be used by decision-makers in the sea level community. Among the errors sources we will investigate are:

1) Error caused by the changing number of tide gauges through time.
2) The error caused by the altimeter data not spanning the variance of the century-long sea level record.
3) Random error caused by tide gauge errors, altimeter errors, etc.

Figure 4 shows an example of a reconstruction of GMSL using the available tide gauge and altimeter data, as compared to the *Church and White* [2006] reconstruction. We have only reconstructed sea level from 1950-2000, because the availability of fewer tide gauges before 1950 requires adjustments to the reconstruction techniques (reducing the number of EOFs, etc.)

Our recent efforts have been focused on understanding the errors in the reconstruction, so that we can better judge how significant the detection of an acceleration is [*Church and White*, 2006]. As part of developing an error budget for the reconstruction, we have been conducting simulations using the output of the Parallel Climate Model, as discussed below.

FY2006 Progress

In order to understand the impact of the reconstruction techniques and their errors on the recovered GMSL record, we conducted sea level reconstruction simulations using output from the Parallel Climate Model (PCM) [*Jakub*, 2006]. Basically, we take the model output, simulate both a 13-year altimeter record (1987-2000) and a 100-year tide gauge record (1900-2000), and then try to recover the PCM global mean sea level variations using EOFs of the alimeter record combined with the simulated tide gauge data. Figure 5 shows the results of this simulation. It shows a) the true GMSL variations computed from the PCM model, b) the reconstructed GMSL sea level record, and c) the sea level record constructed from a simple weighted average of the tide gauge data. Figure 6, which shows the difference between the true and reconstructed sea level records, similarly illustrates this. Not surprisingly, the reconstruction performs better after 1987, when the altimeter data better describes the sea level variance.

The reconstruction simulation using the PCM model has been a very useful tool for understanding the different errors inherent in such techniques. The results of the simulation are being used to assemble an error estimate that can be applied to reconstructions using real altimeter and tide gauge data.

References

Chambers, D. P., et al. (2002), Low-frequency variations in global mean sea level: 1950–2000, *J. Geophys. Res.*, *107*, 1-1 to 1-10.

Church, J., and N. J. White (2006), A 20th century acceleration in global sea-level rise, *Geophys. Res. Lett.*, *33*, doi:10.1029/2005GL024826.

Jakub, T., A Sensitivity and Error Analysis of a Sea Level Reconstruction Using Satellite Altimeter and Tide Gauge Data (2006), M.S. Thesis, University of Colorado, Boulder.

Nerem, R. S., and G. T. Mitchum (2001a), Observations of Sea Level Change from Satellite Altimetry, in *Sea Level Rise: History and Consequences*, edited by B. C. Douglas, et al., pp. 121-163, Academic Press.

Nerem, R. S., and G. T. Mitchum (2001b), Sea Level Change, in *Satellite Altimetry and Earth Sciences: A Handbook of Techniques and Applications*, edited by L. Fu and A. Cazenave, pp. 329-349, Academic Press.

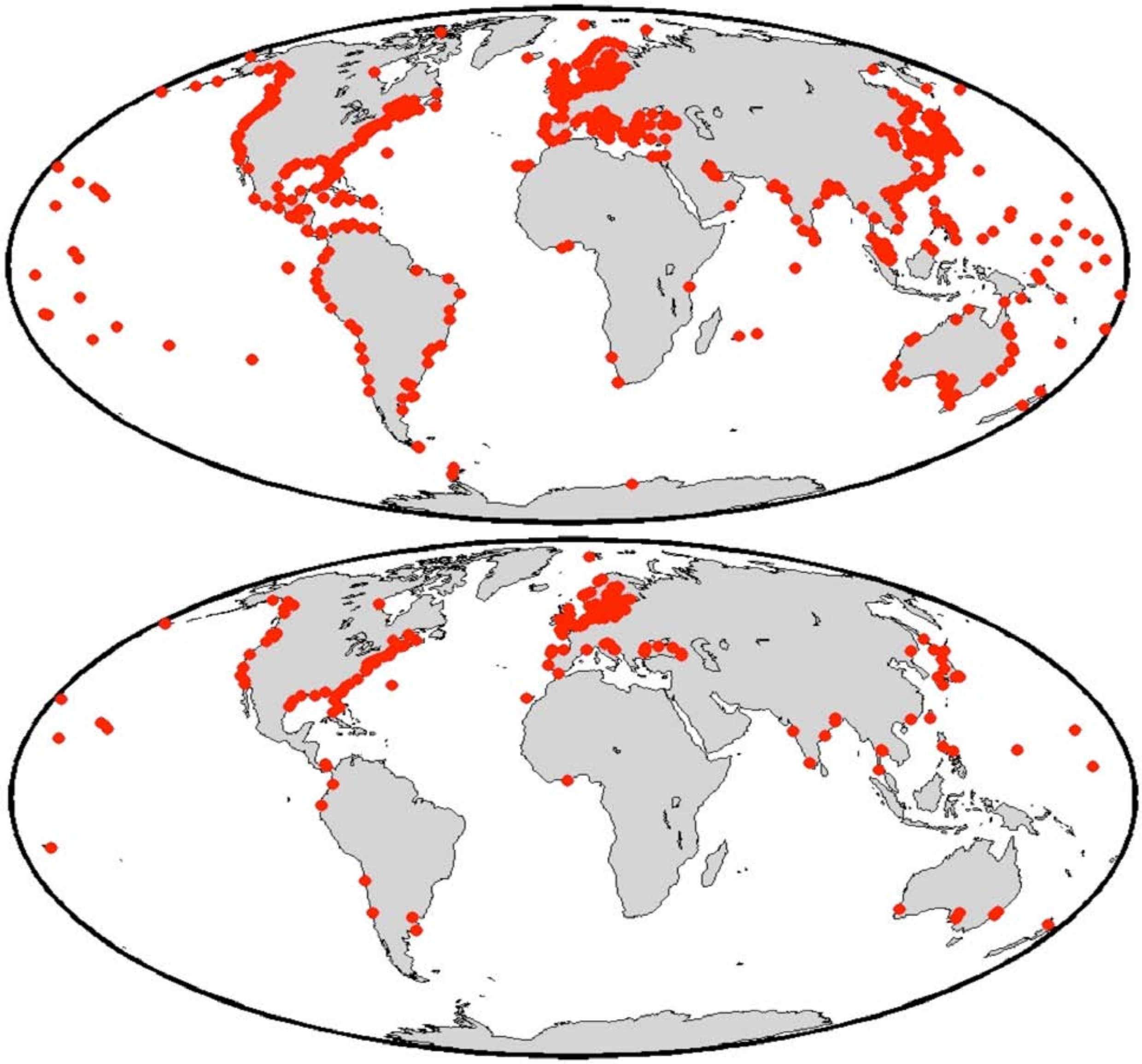

Figure 1. Tide gauge records in the holdings of the Permanent Service for Mean Sea Level (PSMSL) that have records longer than 10 years (top) and 50 years (bottom).

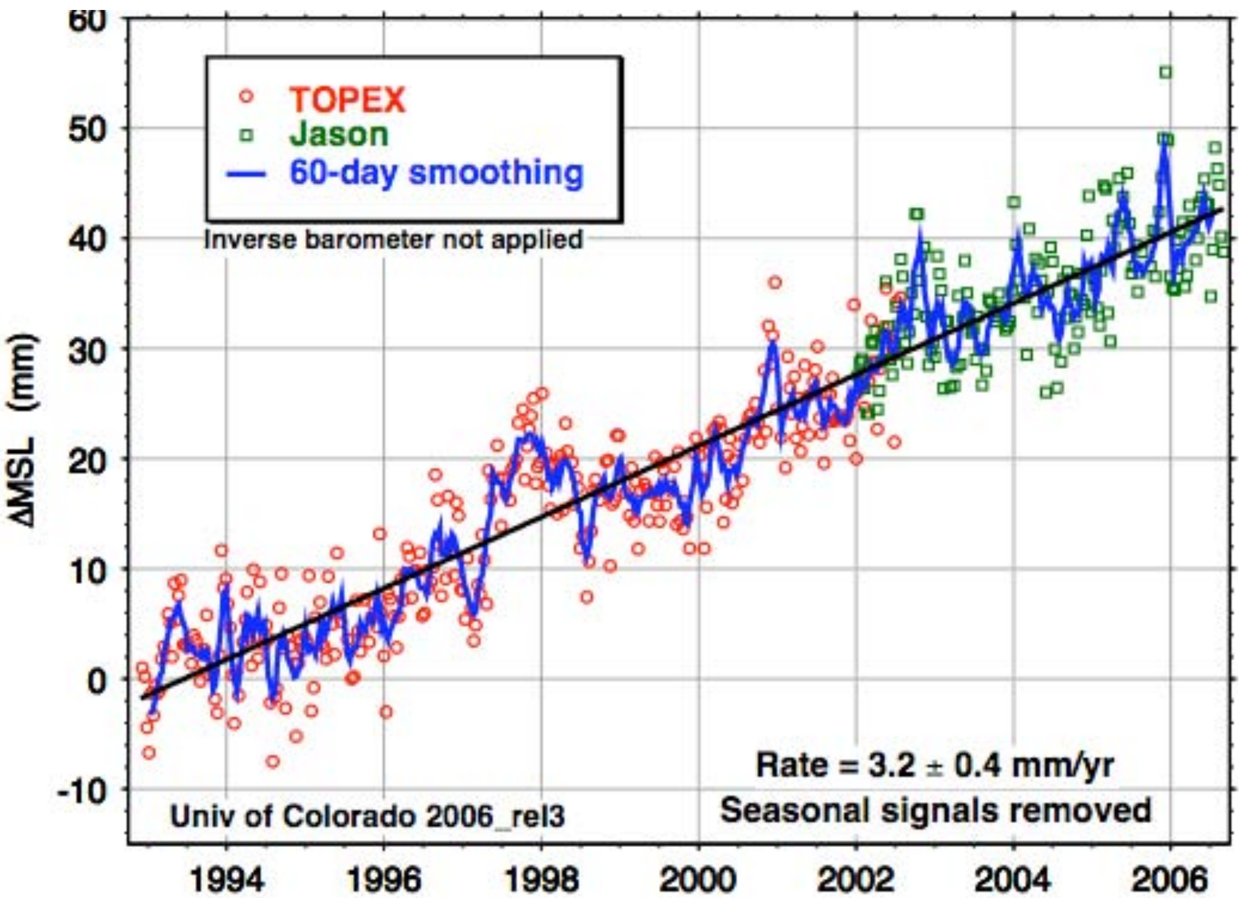

Figure 2. Global mean sea level (GMSL) reconstruction derived from a combination of TOPEX and Jason satellite altimeter data (1993-present) and globally distributed tide gauge measurements (1920-present).

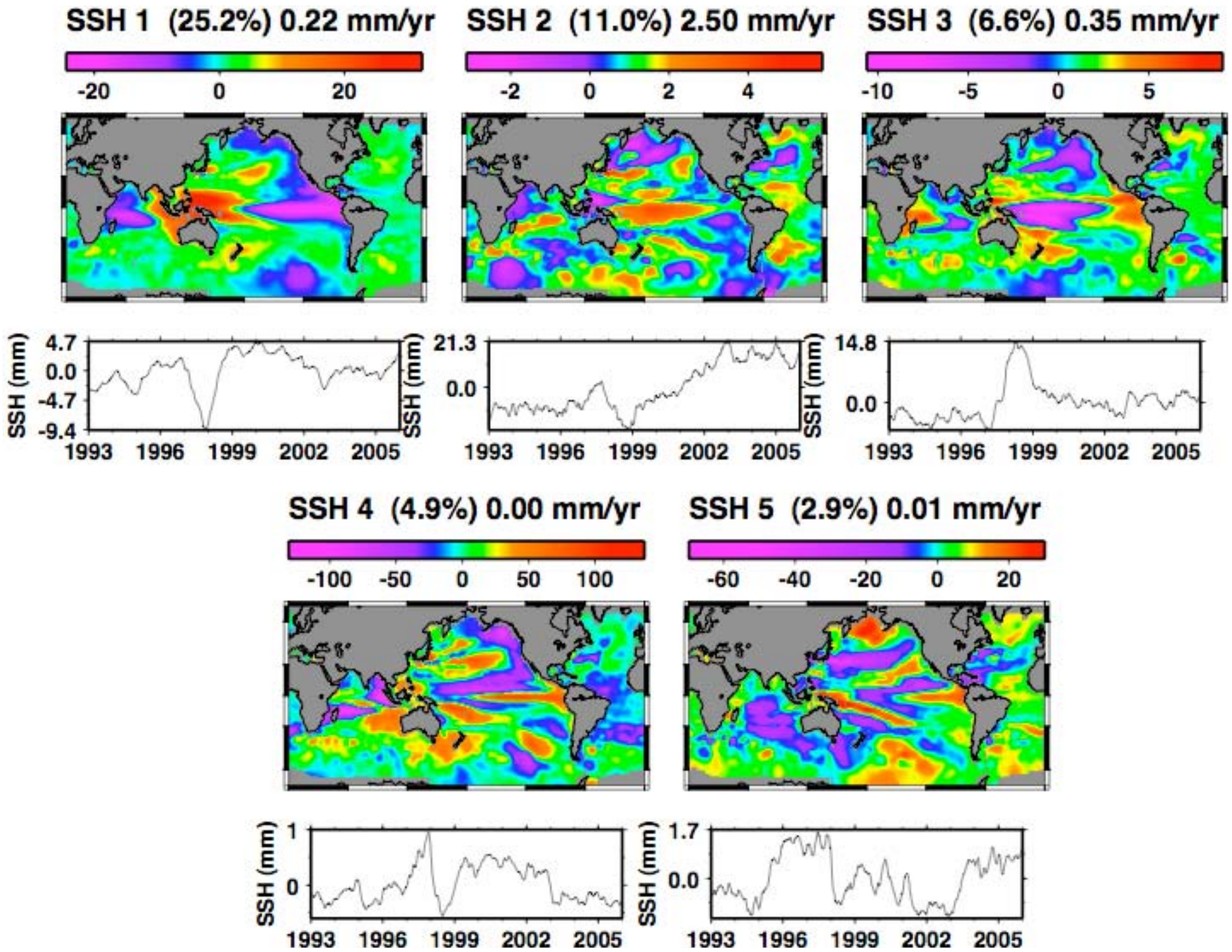

Figure 3. Empirical Orthogonal Function (EOF) decomposition of sea level variations from the TOPEX/Poseidon and Jason missions (first 5 modes only).

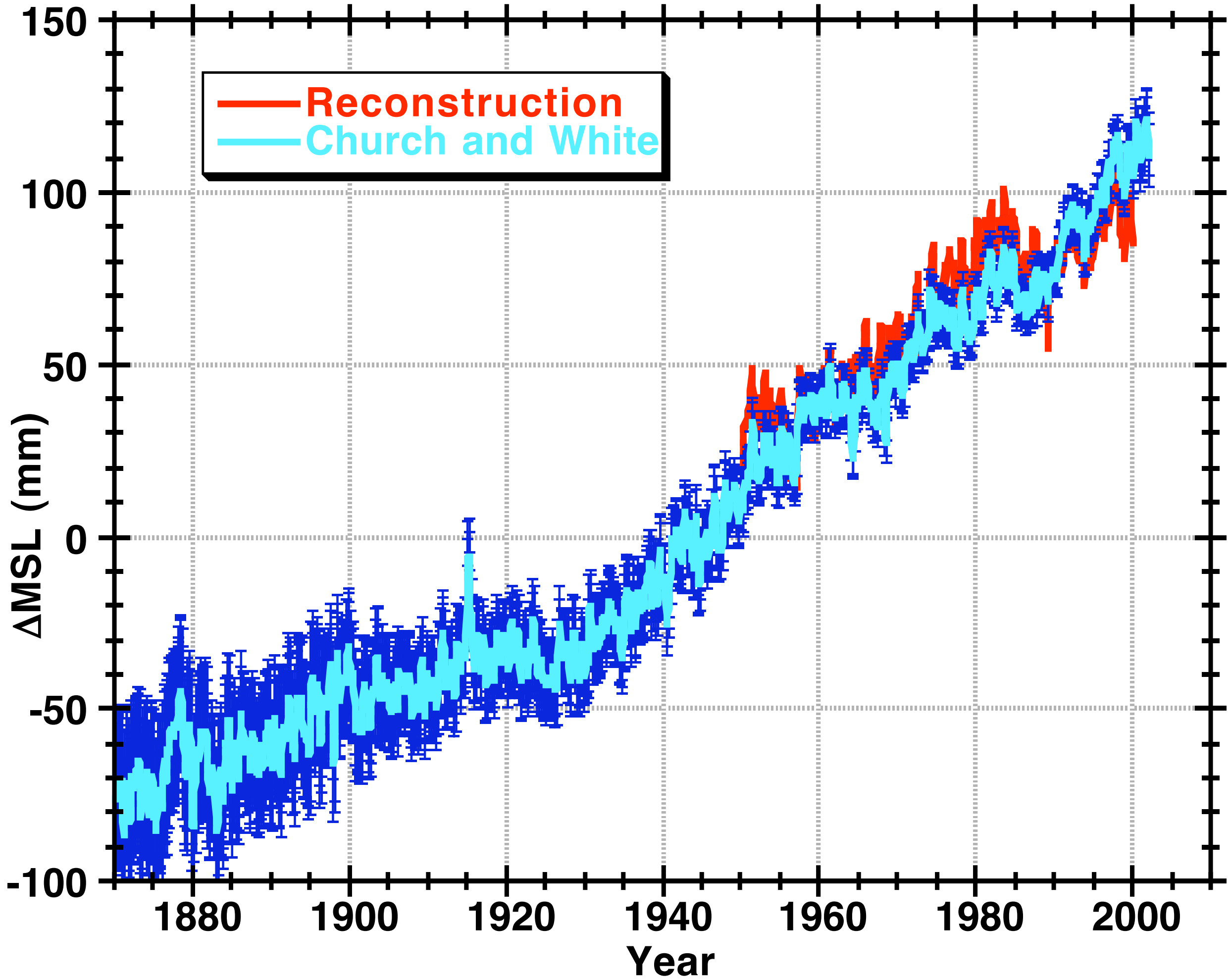

Figure 4. A comparison of two global mean sea level (GMSL) reconstructiosn derived from a combination of TOPEX and Jason satellite altimeter data (1993-present) and globally distributed tide gauge measurements (1870-present) [Church and White, 2006].

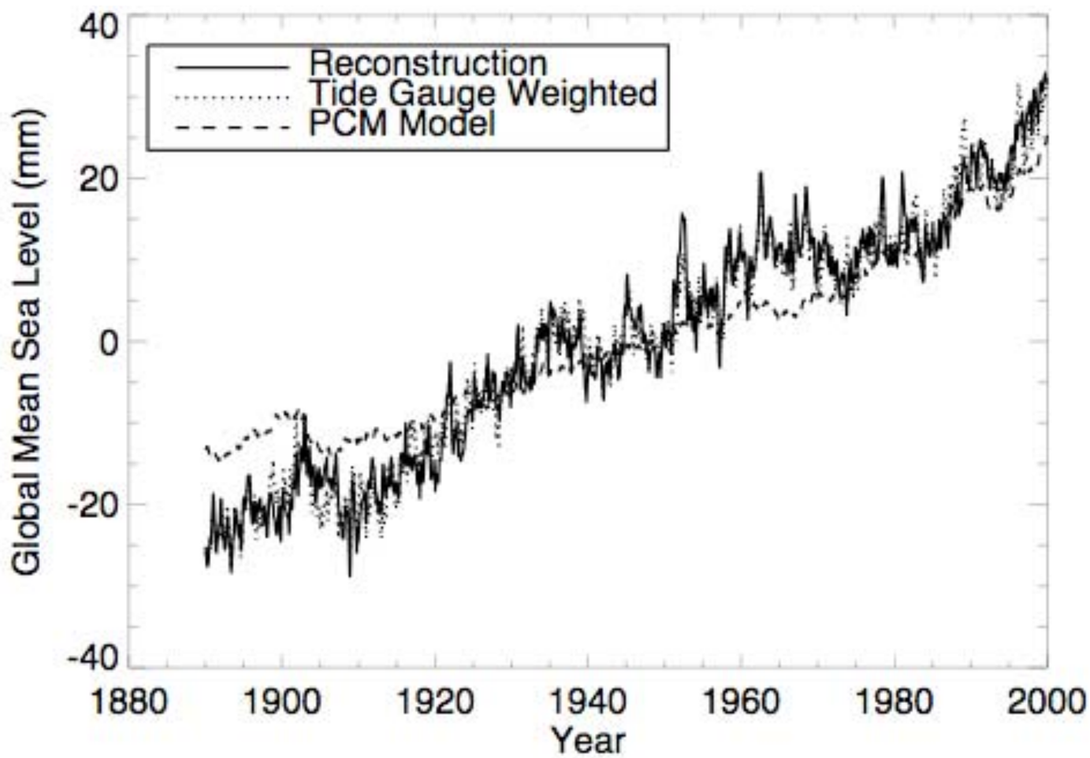

Figure 5. Time series of GMSL from the PCM model, the weighted tide gauges and a reconstruction from simulated altimeter and tide gauge data.

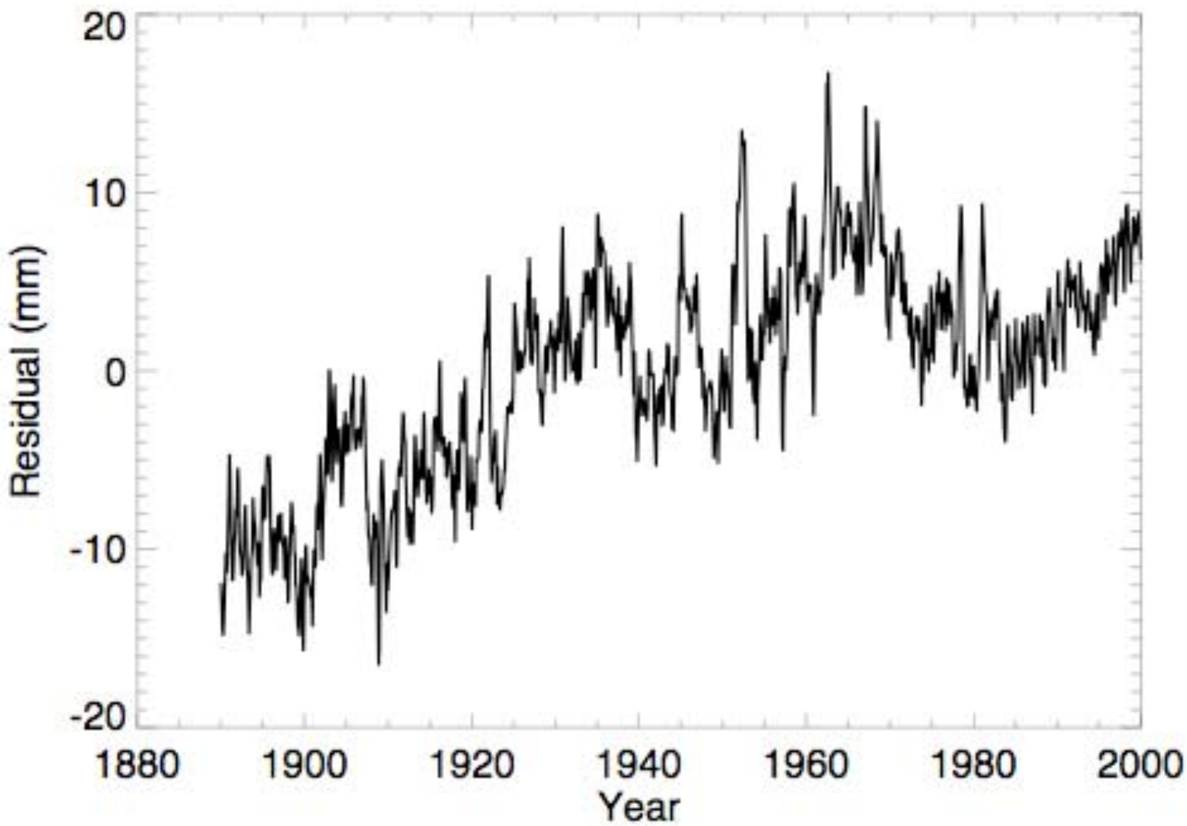

Figure 6. The difference of GMSL residual between the reconstruction and the PCM model has a different amount of variance before and after 1987 (corresponding to when the simulated satellite altimeter data begins), 5.85 mm^2 and 36.81 mm^2 respectively.